

**TITLE**

**SIGNAL TESTING OF INTEGRATED CIRCUIT CHIPS**

**BACKGROUND OF THE INVENTION**

**Field of the Invention**

5 The invention relates to integrated circuits, and more particularly to a mechanism for testing and fine-tuning the signal quality of integrated circuit (IC) chips.

**Description of the Related Art**

In computer systems, the general method for improving 10 the data transfer rate is to raise the bus frequency or increase the data bus width. Growing bus width significantly increases the I/O density of IC chips. Although this is a common method in recent years, a great 15 increase in the I/O density causes computer systems to be more susceptible to electromagnetic interference (EMI) caused by higher frequencies, and presents a difficult challenge in IC design, board layout and PCB manufacture.

Today, the most commonly encountered noise problems in high-speed systems are ground bounce and power bounce. The 20 basic form of ground or power bounce occurs when the IC chip has multiple output pins changing state simultaneously. Such bounce types are referred to as simultaneous switching output (SSO) noise. For example, the least significant bit (LSB) of an 8-bit output is in the low state and the others 25 are switching from high to low, that is, from "11111110" to "00000000". This creates an induced voltage across the parasitic inductance in the ground lead of the IC chip. Because the parasitic inductance is between the external

system ground and the internal IC chip ground, the induced voltage causes the internal ground to be at a different potential than the external ground. This induced voltage is known as ground bounce as shown in FIG. 1. In this case, 5 ground bounce on the LSB in the low state may be substantial enough to cross the input threshold of a subsequent device, which in turn can cause this device to misinterpret the static LSB as a logic "1". Power ground is the inverse of ground bounce. For example, the most significant bit (MSB) 10 of an 8-bit output is in the high state and the others are switching from low to high, that is, from "10000000" to "11111111". This creates an induced voltage across the parasitic inductance in the power lead of the IC chip. FIG. 2 shows an exemplary graph of power bounce. In this case, 15 power bounce on the MSB in the high state may be substantial enough to drop below the input threshold of a subsequent device, which in turn can cause this device to misinterpret the static MSB as logic "0".

Ground and power bounce problems can result in the 20 unexpected, unreliable, and sometimes intermittent, behavior of a computer system. As data transfer rate increases, SSO noise becomes a crucial issue for high-speed IC design. Therefore, what is needed is a way for IC chips to quickly detect and effectively defeat SSO noise.

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#### SUMMARY OF THE INVENTION

It is an object of the present invention to provide a method of signal testing, which permits an IC chip to easily and autonomously detect ground bounce and power bounce problems.

It is another object of the present invention to provide a signal adjustment method for IC chips to perform an internal adjustment automatically in order to overcome ground bounce and power bounce.

5 The present invention is generally directed to a method for testing signals of integrated circuits. According to one aspect of the invention, a first IC chip successively drives a plurality of test patterns one at a time. At a second IC chip, these test patterns are received to latch in 10 one by one. Meanwhile, the second IC chip determines whether a currently latched test pattern is correct or not. If at least an error bit occurs in the currently latched test pattern, the second IC chip can indicate that there exists noise interference in a signal trace corresponding to 15 the error bit. The above steps are repeated until the first IC chip finishes driving the test patterns.

According to another aspect of the invention, a plurality of test patterns are received and latched in one by one through an agent in integrated circuits. In the mean 20 time, the agent determines whether a currently latched test pattern is correct or not. When at least an error bit occurs in the currently latched test pattern, the agent indicates that there exists noise interference in a signal trace corresponding to the error bit. In this case, the 25 agent can adjust a reference voltage level in accordance with the type of the test pattern to change its input threshold. To change the output timing of the pin relative to the error bit, if necessary, the driving capability of that pin is further adjusted for the agent.

#### **DESCRIPTION OF THE DRAWINGS**

The present invention will be described by way of exemplary embodiments, but not limitations, illustrated in the accompanying drawings in which like references denote 5 similar elements, and in which:

FIG. 1 is a graph illustrating an exemplary waveform of ground bounce;

FIG. 2 is a graph illustrating an exemplary waveform of power bounce;

10 FIG. 3 is a flowchart of a preferred embodiment in accordance with the invention;

FIG. 4 is a diagram illustrating the adjustment of input threshold by altering the reference voltage level in accordance with the invention; and

15 FIG. 5 is a diagram illustrating the adjustment of output timing by altering the driving capability in accordance with the invention.

#### **DETAILED DESCRIPTION OF THE INVENTION**

The present invention exploits fixed and predictable 20 test patterns to generate the simultaneous switching effects on board traces between driver and receiver IC chips as well as I/O pins thereof. In this manner, the potential problems of ground bounce and power bounce between the driver and receiver IC chips can be detected accordingly. The receiver 25 IC chip automatically changes a reference voltage level to adjust its input threshold when an error is detected. If the error still occurs, the driver IC chip can further alter its driving capability to adjust output timing thereby avoiding running into ground or power bounce.

In accordance with the invention, driver and receiver IC chips individually have three types of built-in test patterns including a ground bounce type, a power bounce type and a heavy load type to detect various noise problems.

5 With respect to the ground bounce type, a driver IC chip drives an initial test pattern consisting of all "1" and drives the remaining test patterns having bits transitioning to "0" from LSB to MSB sequentially. Taking 8-bit test patterns as an example, those patterns involved in the

10 ground bounce type are driven in order as follows: "11111111" -> "11111110" -> "11111100" -> ... -> "10000000" -> "00000000". A receiver IC chip can accept such test patterns to determine whether any noise problems occur accordingly. With respect to the power bounce, the driver

15 IC chip drives an initial test pattern consisting of all "0" and drives the remaining test patterns having bits transitioning to "1" from LSB to MSB sequentially, that is, "00000000" -> "00000001" -> "00000011" -> ... -> "01111111" -> "11111111". In the case of the heavy load type, the

20 driver IC chip drives a test pattern consisting of all "1" and switches the test pattern from all "1" to all "0" simultaneously except the LSB. This evaluates the LSB for ground bounce under a heavy load condition. Then the driver IC chip drives the test pattern consisting of all "1" again

25 to evaluate the LSB for power bounce under the heavy load condition. After that, the test pattern is switched from all "1" to all "0" simultaneously except the MSB to evaluate the MSB for ground bounce under the heavy load condition. Finally, the driver IC chip drives the test pattern

30 consisting of all "1" again to evaluate the MSB for power

bounce under the heavy load condition. In other words, the test patterns involved in the heavy load type are driven in order as follows: "11111111" -> "00000001" -> "11111111" -> "10000000" -> "11111111". Additionally, the driver and the receiver IC chips both have an input pin to enable the inventive self-test mode; they also include a group of output pins to indicate a test error and its test pattern in accordance with the invention.

The features of the present invention will now be described in detail from a flowchart of FIG. 3. If the aforementioned input pins are fed with a specific signal to enable the self-test mode of the invention, then a first IC chip successively drives a number of test patterns one at a time (step S310). At a second IC chip, these test patterns are received to latch in one by one (step S320). Now the first IC chip serves as a driver while the second IC chip plays a receiving role. The second IC chip then determines whether a currently latched test pattern is correct or not (step S330). If at least an error bit occurs in the currently latched test pattern, the second IC chip can indicate that the error is caused by which test pattern (step S340). According to the type of that test pattern, the second IC chip also shows that there exists noise interference in a signal trace or I/O pin corresponding to the error bit. Once the currently latched test pattern is incorrect, the second IC chip automatically adjusts a reference voltage level  $V_{REF}$  based on the related test pattern type to change an input threshold of the second IC chip. Optionally, the first IC chip can further adjust a driving capability of a pin relative to the error bit to

change that pin's output timing in order to avoid encountering noise interference (step S350). The first IC chip drives the next test pattern automatically if the reference voltage level and/or the driving capability are 5 adjusted properly (step S360). At the moment, this test pattern is checked to determine if it is the last one (step S370). If not, the above steps are repeated until the first IC chip finishes driving all test patterns. When finished, the first and the second IC chips decide whether the driver 10 and the receiving roles should be reversed (step S380).

In general, the input threshold of a digital IC chip is dependent on the reference voltage level  $V_{REF}$ . Furthermore, the digital IC chip latches in input data on the basis of its operating clock. If the input data is latched above 15  $V_{REF}$ , the digital IC chip determines that the latched data is a logic "1"; if the input data is latched below  $V_{REF}$ , the digital IC chip determines that the latched data is a logic "0". Since  $V_{REF}$  is typically supplied by a voltage divider that is made up of external resistors, prior arts usually 20 change the external resistors to manually adjust  $V_{REF}$ . In accordance with the invention,  $V_{REF}$  can be adjusted by changing an internal register setting of the receiver IC chip. In one embodiment, the reference voltage level is adjusted in a unit of 0.01 volts at a time and its 25 cumulative adjustment is limited to  $\pm 0.1$  volts. Further, the driving capability can be altered to adjust the output timing by changing an internal register setting of the driver IC chip. In one embodiment, the output timing is changed in a unit of 150 ps at a time and its cumulative 30 adjustment is limited to  $\pm 300$  ps. The countermeasures

against the power and bounce problems by means of altering the reference voltage level are illustrated in FIG. 4. In the case of the error caused by a test pattern belonging to the power bounce type,  $V_{REF}$  is decreased to lower the input 5 threshold of the receiver IC chip, i.e.,  $V_{REF}=V_{REF}-0.01V$ . In the case of the error caused by a test pattern belonging to the ground bounce type,  $V_{REF}$  is increased to raise the input threshold of the receiver IC chip, i.e.,  $V_{REF}=V_{REF}+0.01V$ . To advance the output timing of the pin relative to the error 10 bit, the driver IC chip increases the driving capability of that pin. Conversely, the driving capability of that pin is decreased to delay the pin's output timing. Referring to FIG. 5, waveform D is the original output signal, waveform D-150ps represents the output signal subjected to an 15 enhancement of driving capability, and waveform D-300ps represents the output signal subjected to a further enhancement of driving capability. With respect to an operating clock CLK, the waveform D-150ps is advanced by a time of 150 ps and the waveform D-300ps is advanced by a 20 time of 300 ps. By fine-tuning the output timing, a digital logic system can avoid encountering noise during the time that data is latched in.

In view of the above, the present invention discloses three types of test patterns for automatic detection of 25 ground bounce and power bounce problems. The invention also proposes a way to overcome noise interference by means of adjusting the output timing and input threshold. Therefore, ground bounce and power bounce problems can be easily tested for in IC chips without the use of expensive instruments. 30 With the help of the invention, it is not necessary to

change circuit design or PCB layout to solve system problems caused by ground bounce and power bounce, and the product development time and cost can be reduced accordingly.

While the invention has been described by way of example and in terms of the preferred embodiments, it is to be understood that the invention is not limited to the disclosed embodiments. To the contrary, it is intended to cover various modifications and similar arrangements (as would be apparent to those skilled in the art). Therefore, the scope of the appended claims should be accorded the broadest interpretation so as to encompass all such modifications and similar arrangements.